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BRIEF COMMUNICATION

Automatic compensation by capillary gauge for altitude decompression

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Mackay, R. S. 1976. Automatic compensation by capillary gauge for altitude decompression. Undersea Biomed. Res. 3(4):399–402.—According to simple theory, the indications of a capillary depth gauge are such that ascent rate and decompression-stop position are correct to give unaltered gammas (tissue overpressures) and a safe dive profile—independent of the density of the medium or of surface altitude—if position indications are used directly in a standard decompression table. The usual dial depth gauges must be doubly corrected for altitude but not medium before tables can be used, while distance-measuring systems should be corrected for both altitude and medium. The capillary-gauge dive profile is theoretically conservative when timed step decompression rather than continuous ascent is used if γ increases with altitude.

depth gauges — altitude diving
decompression — equivalent depth
Haldane model — corrections for altitude

A recently decompressed diver should not take airplane rides or mountainous automobile journeys soon after surfacing, but there are also hazards when a diver starts and finishes a dive in lakes (or does tunnel work under pressure) at altitudes above sea level, if one assumes the normal decompression tables remain valid. These matters were discussed at a Lake Tahoe NAUI conference in August 1974, at which the original 1965 work of Pegg was also discussed. The presentation by Bell was amplified into a recent paper (Bell and Borgwardt 1976).

In practice, the results with free divers depend upon how the depth indication is interpreted. Different gauges give different values. The purpose of this communication is not to give new decompression tables or to discuss the correctness of the Haldane model, but rather to indicate the trends imposed on a table derived from such a model by the use of different types of gauges.

The previous machinery of computation (for example, Bradner and Mackay 1963) is quite suitable for the calculations that are needed, but a convenience results if one simply assumes an equivalent depth greater than actual which can then be referred to standard tables. Assuming that the critical supersaturation ratios, called gammas (the tissue nitrogen pressure divided by the ambient pressure), are the same for symptoms at the lower pressure of altitude, then still one must not exceed the table gammas at any point. For the gammas to be the same, one can use an *equivalent depth*. This is the actual depth multiplied by the ratio of atmospheric pressure at sea level to that at the location, and, if a lake is the location, also multiplied by the ratio of the densities of fresh to salt water. Equivalent depth is employed throughout: in specifying one's position, in locating decompression stops, and in specifying successive levels through which one passes at the ascent rate allowed by the tables. This last factor gives an actual ascent rate that is reduced because a greater-than-actual depth is apparently traversed at the U. S. Navy rate in the specified time. The magnitude of the effect will depend on how depth is measured if depth gauge readings are simply used directly.

The fathometer

A way of finding actual depth is to lower a rope with a stone on the end and to measure its length. Correction for effective depth, described above, is required. This is also the case if one uses another useful and readily constructed depth gauge formed from a small portable fathometer such as is used on sailboats. The standard small assembly can be placed in a waterproof housing with the ultrasonic transducer outside and separate. Thus the latter can be aimed up to find depth, down to find bottom distance, and ahead to locate obstacles in murk. This unit also measures distance, in terms of the velocity of sound, and requires similar correction.

The velocity of sound in ocean water is about 1.02 times that in fresh water and, thus, depth readings from the fathometer will all be too high and must be corrected by the small factor 0.98. If diving is in fresh water rather than salt, actual depth would be multiplied by this factor, before consulting a decompression table. This factor need not be considered with depth gauges that infer depth from a pressure indication (where the gauge and human body are both responding to pressure and the actual depth is irrelevant).

Bourdon gauges

Most divers carry a dial gauge based upon a Bourdon tube or a diaphram that acts against a metal spring to swing a pointer around the scale in response to pressure differences across the tube or diaphragm. It is initially referenced to a pressure of 1 atm, at which it is set to read zero (hence the term *gauge pressure*). Such a depth gauge will indicate a fresh water depth equivalent that is appropriate for the diver to use as an entry into a decompression table. However, two distinct situations may occur if one is also diving at high altitudes.

Because of the reduced initial pressure at high altitude, the dial indication would tend to swing below zero (at which point there is often fixed a pin or mechanical stop). Thus the pointer does not start to rise with increasing depth until a dive has progressed approximately a meter for every 840 meters of initial altitude, and indications will be correspondingly low at all subsequent depths.

The other case is that sometimes the pointer may slip upon the pivot to indicate zero when the diver is initially at the surface of an elevated body of water. (A similar result is achieved with a controlled leak into the reference chamber. In that case a constant factor is added to all absolute readings. Academic assumptions about degree of slip and scale linearity are involved.) The response of such gauges is not changed—only the initial reading—because increasing pressure acts against an essentially unchanging spring. The usual relationship between gauge and absolute pressure does not exist: depth readings are low if there is no slippage; if there is, absolute readings are increased. Readings can be corrected for this additive offset, but corrections similar to the previous are additionally required before use of tables.

Capillary gauge

The situation with capillary gauges is quite different. In these an initial sample of air is compressed by incoming water according to Boyle's law. When one is at a depth where, say, the volume is one-half, the label indicates 33 ft. If one starts from a lower pressure, the trapped gas will more readily compress; that is, the indication of 33 ft will be achieved at a correspondingly lesser depth where the pressure has become twice the original. All apparent depths are increased over actual by the pressure ratio of the normal pressure of 1 atm to the initial ambient pressure. Since it is this same pressure ratio by which all actual depths and rise rates would have to be corrected for the use of standard decompression tables, according to simple theory a capillary gauge can be used *to guide ascent without correction*. Because an actually smaller distance is covered while apparently transversing a greater one, the reduced ascent rate is effected properly, as are the altered positions of the decompression stops. The total ascent time from a given actual depth is increased. The nature of the medium (fresh vs. salt water) here again does not matter since this is a pressure measurement.

If for the class of dives involved here critical ratios increase somewhat with decreasing absolute pressure, and if decompression is broken into timed steps rather than being continuous throughout, a problem arises with convenient theory (Bell and Borgwardt 1976) since one will remain at stops longer than necessary. The latter authors note that the use of an effective depth yields a dive profile that is conservative, the degree of which depends upon the severity of the dive. The indications of a capillary gauge theoretically yield a similarly conservative dive. Immersion of the gauge in cold water also introduces a small safety factor.

The response of a capillary gauge to altitude can be predicted from Boyle's law. Suppose a bubble of length ℓ in a tube of length ℓ_0 exists at a depth D in the ocean where atmospheric pressure is P. The tube is then immersed in sea water at an altitude where atmospheric pressure is P' to determine the corresponding indicated depth D', giving the same reading ℓ'

$$\ell = \ell' = \ell_0 \frac{P}{P + kD} = \ell_0 \frac{P'}{P' + kD'}$$

from which: $D'/D = P'/P$ where k is a constant.

Thus, such gauges read high at altitude, unlike the usual types which read low, and incorporate in normal functioning a perfected version of what are sometimes called "Cross" or "Pegg corrections." It is still assumed the diver will wait 12 hours for tissue outgassing before diving upon arrival at altitude or else will use some sort of repetitive table.

It might be mentioned that this general problem is separate from that of surfacing after hard work at depth into a region relatively low in available oxygen, which makes repayment of "oxygen debt" difficult.

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Mackay, R. S. 1976. La compensation automatique de la décompression due à l'altitude par un indicatuer à capillaires. Undersea Biomed. Res. 3(4):399–402.—Selon la théorie, les indications d'un indicateur de profondeur devraient être telles que la vitesse de montée et la position décompression-arrêt sont correctes pour indiquer des gammas (surpressions tissulaires) inchangés et un schéma de plongée sans danger—quel que soit la densité du milieu ou l'altitude au surface—si les indications de position sont utilisées directement dans une table standard de décompression. Il faut corriger les indicateurs ordinaires de profondeur deux fois pour l'altitude mais non pour le milieu, avant de se servir des tables, tandis qu'il faut corriger les systèmes qui mesurent la distance pour l'altitude comme pour le milieu. Le schéma de plongée de l'indicateur est théoriquement conservateur si l'on choisit une décompression par étapes plutôt cu'une montée continue, ou le gamma augmente en fonction de l'altitude.

indicateurs de profondeur
décompression
modèle de Haldane
plongée à l'altitude
profondeur équivalente
corrections pour l'altitude

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